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CANTOR LECTURES

ON

LIGHT AND COLOUR.

BY

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SYLLABUS.

LECTURE I.

The production of colour and its dependence on the kind of illuminant.—The spectrum and its recombination.—Simple colours.—The characteristics of colour.—Colours of pigments.

LECTURE II.

Interference colours.—Production of colour by absorption; by fluorescence.—The measurement of the luminosity of colours.—Colour contrast.—Colour-blindness.

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LIGHT AND COLOUR.

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CAPTAIN W. DE W. ABNEY, C.B., R.E., F.R.S.

LECTURE I.—DELIVERED NOVEMBER 26, 1888.

I hold in my hand a series of colours of various hues and depths, some of them are fugitive and others are fast colours, and it is the object of the lectures I have been called upon to deliver to show how we can measure and mix colours, and what causes the fading of some by light. In four lectures this subject can by no means be treated exhaustively, and I can only endeavour to explain, in as familiar language as I can command, and by some plain experiments, what I desire to enforce upon your minds. A great deal has been written in the last two years on the subject of the fading of water-colours, and from what I have gathered from the newspaper correspondence, it is not quite unnecessary that a few familiar discourses on the subject should be given, to prevent a repetition at all events of some of the blunders that have been made in physical phenomena. It may be known to some who are present here to-night that Dr. Russell and myself have carried on a series of experiments during two years on the subject of the fading of water-colours, and as our report to the Science and Art Department, which was presented to Parliament, pleases neither the party who cry out that water-colours are stable, nor yet the party who proclaim the contrary, we may presume that our results are not altogether wrong. To these experiments I shall refer later in the course of lectures.

Now, to commence with the elements of colour from the physicist's point of view. I wish to show you that the colour of an object depends on the composition of the light falling on it, on the material on which such light falls, and on the eye of the person. The screen which I have here is what we call white, when viewed by ordinary daylight or artificial light, and such a screen not only will reflect white light, but also all coloured lights with the greatest brilliancy possible.

Let me throw a spectrum on the screen to serve as a text. If a brilliant spectrum be looked at, we see that it is really divided into three colours, blue, green, and red, with shades of other colours blending these colours into one another. I am not going into the theory of the matter, but I would ask you to remember that the mean red light has a wave length of about 38,000 to the inch, the waves being in the luminiferous ether of whose existence we only know by circumstantial evidence, the green of about 50,000 to the inch, and the violet of about 64,000 to the inch. The other colours have intermediate wave lengths.

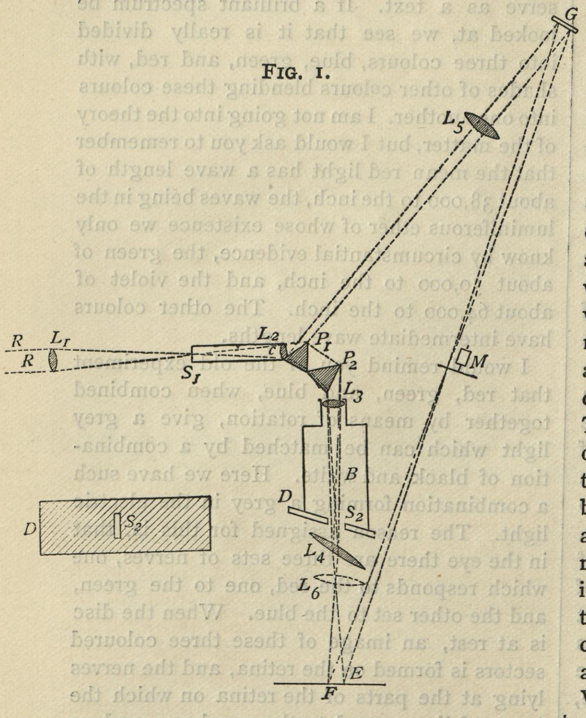
I would remind you of the old experiment that red, green, and blue, when combined together by means of rotation, give a grey light which can be matched by a combination of black and white. Here we have such a combination forming a grey in the electric light. The reason assigned for this is, that in the eye there are three sets of nerves, one which responds to the red, one to the green, and the other set to the blue. When the disc is at rest, an image of these three coloured sectors is formed on the retina, and the nerves lying at the parts of the retina on which the image falls respond to these colours, and we see the sectors coloured. If there is astigmatism, or defects in the optical apparatus of the eye, the image is not sharp, then we have an image of part of the two colours adjacent blended into one another, or again if the discs rotate rapidly, so that the same part of the retina receives the coloured images in quick succession, all three sets of nerves are brought into use, and we have an impression of white, or rather grey, produced. But this subject I shall allude to again in one of my subsequent lectures.

We can recombine also the pure colours of the spectrum by several plans, the simplest to

my prejudiced mind being that which I introduced. I take away the lens of long focus, and put one of shorter focus in its place attached to a camera, for reasons which I will shortly explain (Fig. 1).

On a collimator, G, to which is attached the usual slit, is thrown, by means of a condensing lens, a beam of light, which emanates from the intensely white-hot carbon positive pole of the electric light. The collimating lens, L_2, is filled by this beam, and the rays issue parallel to one another and fall on the prisms, P_1 and P_2, which disperses them. The dispersed beam falls on an ordinary camera lens, L_3, of slightly larger diameter than the height of the prisms, and a spectrum is formed on the focussing-screen, D, of a camera. When the focussing-screen is withdrawn, the rays would form a confused patch of parti-coloured light on a white screen, F, placed some four feet off the camera. The rays, however, can be collected by a lens, L_4, of about two feet focus, placed near the position of the focussing-screen, and slightly askew. This forms an image on the screen of the near surface of the last prism, P_2; and if correctly adjusted, the patch of light should be pure and without any fringes of colour. The card, D, is a strip which fits into the aperture left for the focussing-screen in the camera. In it will be seen a slit, S_2, the utility of which will be explained later on.

FIG. 1.



It often happens that a second patch of white light, comparable to that formed, is required. Advantage is taken of the fact that from the first surface of the first prism P_1, a certain amount of light is reflected. Placing a lens. L_5, in the path of this reflected beam, and a mirror, G, another square patch of light can be thrown on the same screen as that on which the first is thrown, and this second patch may be made of the same size as the first patch if the lens, L_5, be of suitable focus, and it can be superposed over the first patch if required.

We have now a square white patch upon the screen, from the re-combination of the spectrum. If I wish to diminish the brightness of this patch, there are at least two ways in which I can accomplish it. First, by closing the slit of the collimator, and, second, by the introduction of rotating sectors, M, which can be opened and closed at pleasure during rotation in the path of the beam.

The annexed figure (Fig. 2, p. 3) is a bird's-eye view of the instrument. A A are two sectors, one of which is capable of closing the open aperture by means of a lever arrangement, C, which moves a sleeve in which is fixed a pin working in a screw groove; D is an electromotor causing the sectors to rotate, and the aperture in the sectors can be opened and closed at pleasure during their revolution. To show you its efficiency, if I place two strips of paper, one black and the other white, on the screen, and cast a shadow from a rod, by the direct white light on the white strip, and a shadow from the same rod by the reflected light on the black strip of paper, and interpose the rotating sectors in the path of the reflected light, the aperture of the sectors can be closed till the white paper appears absolutely blacker than the black paper. White thus becomes darker than lamp-black, owing to want of illumination on the former.

We all talk about white light; we say that the electric light is white and that gas light is white. I wish to show you that the whiteness is a mere matter of judgment.

I throw the shadow, by the electric light, of a thick rod on white paper, and another shadow by gas light, on the same paper, and we at once see that the shadow illuminated by the electric light seems blue, whilst that illuminated by the gas light appears orange, yet we speak of both gas light and the electric light as white lights. Evidently, if these two differ so much in colour, pigments will take different hues when illuminated by them. Putting

paper coloured with red, blue, and green pigments in the shadows, the change in hue is at once apparent. Placing in the shadow illuminated by the electric light a strip of paper coloured orange (Fig. 3), by orange chrome and aureolin, we see that now the electric light reflected from it appears of very nearly the same hue as the light from the gas reflected from white paper. Gas light, we may say then, is orange rather than white, if we take the electric light as the standard.

We have seen that colours appear of different hue in the electric light to that which they appear in gas light, and I wish to enforce this more strongly upon you by an experiment which I introduced a year ago. In front of the condenser of the electric light lamp I place a circular aperture some inch in diameter, and by means of a lens throw an image of it on a white screen. We may suppose this to represent the sun, the colour of the light being very much the same as that which it has in England about midday in the middle of May. In front of the aperture I place a trough containing a solution of hyposulphite of soda, and then drop into it dilute hydrochloric acid, and stirring up the two together very fine particles of sulphur slowly separate, and the white light, owing to the law of scattering by small particles, loses some of its components, and we have a gradual reddening of the sun—first yellow, then orange, and finally a red—the series forming a very exact representation of the colours of a setting sun. If we place coloured pigments in this changing light, we see how, towards sunset, the blues become darker whilst the reds change but little in hue. It may have been remarked that in an evening the last colours in a picture to disappear are the reds. The colour of sunset light now imitated before you gives a clue to the reason of this.

FIG. 2.

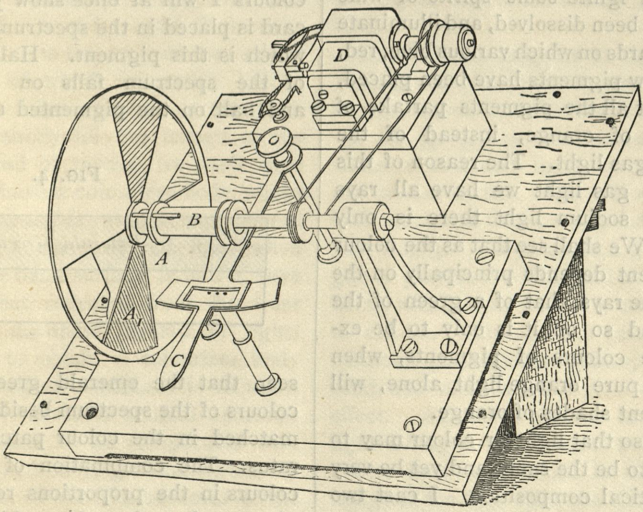
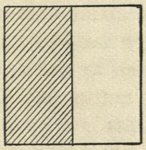


FIG. 3.



We may as well trace the cause of this change in colour. Placing a cell containing hyposulphite of soda in front of the slit of the spectroscope, and throwing the spectrum on the screen, and then adding the dilute hydrochloric acid, we find that as the light from the reflected beam (which we throw just above the spectrum) becomes yellow, orange, and then red, so the spectrum loses the violet, then the blue, then the green, till finally the red alone remain.

Let me further exemplify that you cannot know what effect the colour of the light has upon a colour unless you know its composition.

The slit S_2 in the card D (Fig. 1) can be passed through the spectrum, and as it cuts off all the colours of the spectrum, except that passing through the slit, we have different coloured square patches of light thrown by—

what I will now call—our patch-forming apparatus, the colour of the patch being that of he colour issuing through the slit.

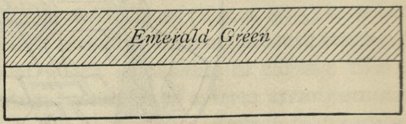
Now sodium, when ignited, gives a peculiar yellow light, due to a line in the orange. If I send the light from this sodium line through the slit S_2, we have a square patch of sodium light on the screen. The rod casts a shadow as before, but instead of casting a second shadow by the reflected beam, I cast a shadow from gas light, when it will be seen that the two illuminated shadows have almost the same colour.

I now shall perform a common Christmas experiment, and ignite some spirits of wine in which salt has been dissolved, and illuminate with that light cards on which various blue, red, green, and yellow pigments have been placed, and we see that all the pigments partake of various shades of orange, instead of the colours seen by gas light. The reason of this is apparent; in gas light we have all rays present, in the sodium light there is only orange present. We shall see that as the colour of a blue pigment depends principally on the reflection of blue rays, that of a green of the green rays, and so on, it is only to be expected that the colours of pigments, when illuminated by pure orange light alone, will only give different shades of orange.

This shows also that light or colour may to the eye appear to be the same and yet be very different in optical composition. I cast two shadows of the rod in the patch-forming apparatus, one by the recombined spectrum and the other by the reflected beam, and pass the card, D, with the slit, S^2. in it along the spectrum. One shadow will be illuminated by the white light and the other by the light from the parts of the spectrum coming through the slit S_2. If I place emerald green in the shadow illuminated by white light, I find that there is one point in the green of the spectrum which matches it in hue, and I can make them of the same depth of colour by the introduction of the rotating sectors. Evidently, then, the coloured light of this part of the spectrum and that of the emerald green might be mistaken for one another, and so with other colours. There are some pigments, however, which cannot be matched by the spectrum colours.

That emerald green is a combination of colours I will at once show you. A strip of card is placed in the spectrum, on one half of which is this pigment. Half of the breadth of the spectrum falls on the white card and half on the pigmented card. It will be

FIG. 4.



seen that the emerald green reflects other colours of the spectrum besides that which it matched in the colour patch-forming apparatus. The combination of all these other colours in the proportions reflected from the pigment, form the colour which, in the simple colour of the spectrum, we should call emerald green. So if we pass other pigments through the spectrum we get similar results, though not all pigments can be so matched.

LECTURE II.—DELIVERED DECEMBER 3, 1888.

In the last lecture I finished the matching of the colour of pigments with parts of the spectrum, and to-night I will endeavour to show you that colourless bodies can be made coloured, under certain conditions, although the light that falls upon them is colourless. I told you last time that the waves of red light are such that if you put 38,000 end to end they make up an inch. If in the sea we have two sets of waves, one set of which is exactly half a wave behind the other, then the crest of the one wave will exactly fill the trough of the other, and instead of motion we shall have rest. Suppose I have a colourless body, whose thickness is comparable with a wave of red light, and that a wave of red light when reflected from the back surface is half a wave length behind that reflected from the front surface, we get darkness instead of light. The easiest way to obtain a colourless body answering to the above conditions is to use a soap film stretched across a vertical aperture. Its thickness is found to be comparable with a wave of light, and as it gradually thins by gravity, some part of the film becomes of the thickness that the reflection from the back surface is half a wave length behind that reflected from the front surface, the red is annihilated at such place. There will be another thickness of film in which the green light would be similarly absent, and yet another in which the blue is absent, and so on. The light reflected from the first locality would be the components of white less the red, in the second the same less the green, and in the third the same less the blue.

I can show you the kind of colour that is seen by the suppression of one small part of the spectrum, by using our patch-forming apparatus and passing a thin rod along the spectrum, which cuts out the part required. It will be seen that the patch is no longer white, but coloured. These colours, remember, are not simple colours, but white light, with some colour abstracted.

Putting a soap film on a ring in the beam of the electric light, at an angle of about 45° with it, the light is reflected on the screen, and a lens in the beam forms an image of the ring. At first the film appars white, but after a short intervals of time coloured bars appear horizontally across it. Putting a piece of red glass in front of the beam, we have a succession of red and black bars, the red glass cutting off all the remaining colours. A piece of green glass placed in the beam shows green bars, and so on.

The bars are brighter at the bottom of the image, which is in reality the top of the film, for the reason that the film is of a thickness of $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, $4\frac{1}{2}$, $5\frac{1}{2}$, &c., wave lengths of the different coloured lights as we go from the top to the bottom of it. The bars gradually widen out and become very far apart, until we see only 3. I now cause a gentle current of gas to play on the film, and the coloured glass being withdrawn, we get a magnificent series of colours whirling one around the other. Peacock green, golden yellow, azure blue, succeed one another, and give a most brilliant effect. All these colours are due to white light falling on a colourless body.

The next experiment is to throw a small image of the film upon the slit of the spectroscope. We see the spectrum traversed by black lines curving down from red to blue, and rapidly shifting in position. These lines show the colours which are absent in the horizontal bars of coloured light reflected from the film, a section of which passes through the slit.

In this case we have a demonstration that the colours reflected from the film are not produced by any conversion of white light into coloured light, but by the abstraction of certain colours from the components of white light.

In the opal we have an example of interference colours, caused by a thin layer of material of different thicknesses, which abstract a certain component of white light in exactly the same manner as does the soap film. When we have the light from the varying thicknesses close together, as we have in the reflected beam in the patch-forming apparatus, they have very much the same appearance as has the opal.

But one more example of interferences,

which is very beautiful, as time will not allow me to go into the theory of the matter; suffice it to say that if parallel lines be ruled on a surface very close together, and the beam of light be thrown on them, the "interferences" are such that pure colours are produced, and we have a spectrum.

Next let me show you that the colour of transparent bodies is also due to the abstraction of colour or colours from the white light.

In a cell I have a liquid which appears green. A spectrum is formed on the screen and in front of the slit of the spectroscope the cell is placed. You will see that the blue and most of the red is cut off, and that we only have the green and a small band in the red left of the spectrum. Recombining the remainder of the spectrum to form a patch as before, we have a square of green light, and side by side with it is the patch formed by the reflected beam, which is coloured by the light which has not passed through the prisms, but only through the cell and the collimator. They are both absolutely of the same hue, showing that the recombined spectrum gives the same colour as the light after passing through the cell. Repeat the same with a red liquid or a blue liquid, and we obtain the same results.

A paper is coloured with the green dye which I had in the cell, and I allow the patch of white light to play on it, and you see the light reflected from it is green. In the path of the *reflected* beam I place a cell containing the green liquid, and throw the patch on *white* paper. The two patches, viz., the white light on the green paper, and the green light on the white paper, are the same colour. The white light which penetrates colouring matter is the same in the two cases, though when on the paper itself it traverses the colouring matter twice. This leads to an important axiom, viz., that the effect is the same whether the colouring matter is in contact with the paper or at a distance from it, so long as the eye receives the light which has traversed such colouring matter. I shall immediately take advantage of this, for I wish to show you that the depth of colour depends on the thickness of colouring matter through which the light passes. Of a double wedge-shaped trough, half is filled with pure water, and the other half with coloured water. Different thicknesses of the blue colouring matter are passed in front of the slit, and as the thickness is increased so the spectrum gets fainter in the blue than in the red.

The patch of white light is next formed, and the wedge of coloured liquid is again passed across the slit, and you will see that the colour deepens as it passes through different thicknesses. As this is true when the colouring matter is in front of the light, so must it be true when the colouring matter is in contact with the papers.

There is another feature which I must not pass over, *i.e.*, what is known as fluorescence, and though it does not enter into the effect of pigments used in water colours, yet it has much to say to the coloured materials of every-day wear. One of the most beautiful examples of this fluorescence is fluorescene. In the beam of the electric light a jar of water is placed, and in it is dropped a concentrated solution of the fluorescene. We have a fine example of fluorescence; the fine threads of liquid as they stretch towards the bottom appear of a brilliant green. I take another jar and repeat the same with quinine sulphate, and we have a gorgeous blue.

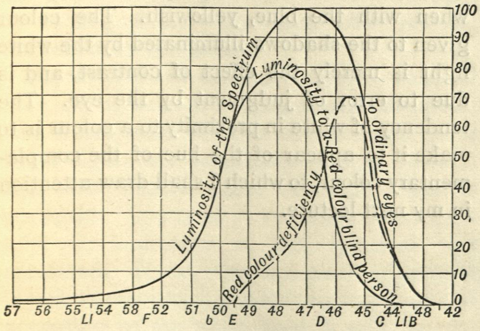
We will endeavour to trace this fluorescence to its source. I take a piece of card and brush it over with the solution of fluorescene, and place it in our colour patch; the different colours of the spectrum illuminate one after the other; we now can readily see the light which causes this fluorescence. It is the green and the blue, but the light reflected from the fluorescene is of a totally different hue from the rest of the colour patch. So with the quinine. We see that when the colour patch is apparently dark, the paper covered with quinine shines out with peculiar lustre. The rays which excite fluorescence in this case are the invisible rays in the ultra violet. Common machine oil is fluorescent in the same part of the spectrum, but shines with a greenish light, and not blue.

We now come to the point when we must ascertain the second constant of colour, viz., its luminosity or brightness. Before showing how this is done for pigments, it will be necessary to show you how we can ascertain the luminosity of the spectrum itself. The luminosity of the spectrum varies greatly in different parts, the maximum luminosity of the prismatic spectrum derived from bright lights, such as the electric light, being in the yellow, and there is a degradation of brightness as we go towards each end of the spectrum. Now suppose we find that the reflected beam of white light, when the rotating sectors are as widely open as possible, is slightly brighter than a yellow patch formed from the yellow of the spectrum

—it is manifest that other parts of the spectrum will be dimmer than that. If, now, in the reflected beam, I rotate the sectors at less than full aperture, less light will reach the screen, and it is evident that there are two parts of the spectrum, one on each side of the yellow, which will match the brightness of this degraded white.

In order to make this match, we place the rod as before in front of the colour patch. One shadow is thrown on the white screen by the spectrum colour, and another shadow is thrown alongside it from the reflected beam. The white light and the coloured light, each light up one of the shadows. The slit in the card is moved across the spectrum till we find (say) that when in the blue the illuminated shadow is too dark, and when the slit is in the green the green illuminated shadow is too light. It is evident that at some intermediate place in the spectrum the coloured shadow is neither too light nor too dark. This place in the spectrum is found by moving the slit rapidly, making the coloured shadow first too light and then too dark, diminishing the extent of the oscillations till equality of brightness is seen to the eye. The same procedure is carried on on the red side of the yellow. The angular aperture of the sectors is again altered, and a fresh determination made. Now the card in which the slit is cut carries a scale, and by means of a pointer the scale is read off, which tells us the exact part of the spectrum where the different equalities of brightness are established. We then use the apertures used as giving the relative luminosities of the different parts of the spectrum as measured, and make such a curve as we have below.

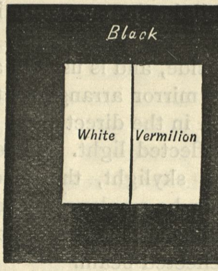
FIG. 5.



The method, then, of ascertaining the luminosity of a colour depends on the rapid oscillation of either the white or coloured patch between "too light" and "too dark."

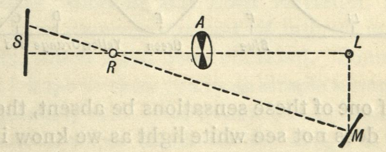
This gives us a clue by which we can measure the luminosity of a coloured surface in a direct manner. The rotating sectors in Fig. 2 give us the means of doing this in an easy manner. Suppose the luminosity of a vermilion-coloured surface had to be compared with a white surface when both were illuminated, say, by gas light, the following procedure is adopted:—A square space of such a size is cut out of black paper so that its side is rather less than twice the breadth of the rod used to cast a shadow. One half of the aperture is

FIG. 6.



filled with a white surface, and the other half with the vermilion-coloured surface. The light, L, illuminates the whole, and the rod, R, is placed in such a position that it casts a shadow on the white surface, the edge of the shadow being placed accurately at the junction of the vermilion and white surface. A flat silvered mirror, M, is placed at such a distance and at such an angle that the light it reflects casts a second shadow on the vermilion surface. Between R and L is placed the rotating sectors, A. The white strip is caused to be evidently too dark and then too light by altering the aperture of

FIG. 7.

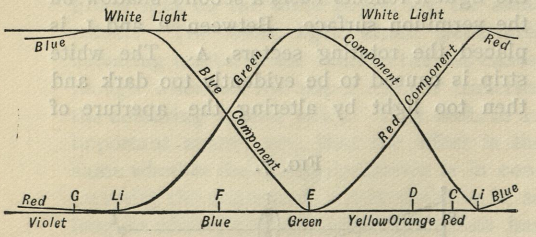


the sectors, and an oscillation of diminishing extent is rapidly made till the two shadows appeared equally luminous. A white screen is next substituted for the vermilion, and again a comparison made. The mean of the two sets of readings of angular apertures give the relative value of the two luminosities. It must be stated, however, that

if the screen remained unshaded, as represented, the values would not be correct, since any diffused light which might be in the room would relatively illuminate the white surface more than the coloured one. To obviate this the receiving screen is placed in a box, in the front of which a narrow aperture is cut just wide enough to allow the two beams to reach the screen. An aperture is also cut at the front angle of the box through which the observer can see the screen. When this apparatus is adopted, its efficiency is seen from the fact that when the apertures of the rotating sectors are closed the shadow on the white surface appears quite black, which it would not have done had there been diffused light in any quantity present within the box. The box, it may be stated, is blackened inside, and is used in a darkened chamber. The mirror arrangement is useful, as any variation in the direct light also shows itself in the reflected light. Instead of gas light, reflected skylight, the electric light, or sun light can be employed by very obvious artifices, in some cases a gas light taking the place of the reflected beam.

It will be in your recollection that I said that the colour of an object depended on the eye of the observer. Vision, I have told you, depends on the fact that three colour sensations are necessary for the normal eye to see white light. There are in fact, as I have said, three sets of nerves, one responding to the blue, one to the green, and one to the red.

FIG. 8.



If one of these sensations be absent, then the eye does not see white light as we know it, but as—what would to us be—coloured light. The above diagram shows the three sensations derived from Clerk Maxwell's measures. The top line is supposed to be the spectrum as the eye sees it, all colours being of equal value. It will be noticed that at only three places in the spectrum is the colour due to single colour sensations, and all intermediate colours are made up by mixtures of two sensations, the height of the curves added together giving the height of the straight line parallel to the base of the curve.

Now, in order to test the eye for colour-blindness, it is only necessary to get a person so afflicted, to measure the luminosity of the spectrum. For evidently, if deficient (say) in red sensation, the spectrum would begin where the green colour sensation commences, and even then the luminosity would be much smaller, owing to the absence of such red sensation. Such a luminosity curve is seen in Fig. 5 (p. 7), and in the same figure is shown the colour deficiency. It is comparatively easy to show the colour of the light which colour-blind people see. If a certain proportion of the light near the position which the blue lithium line occupies in spectrum be mixed with a certain proportion of the green light of the spectrum near E, and the two be combined in a patch, the colour of the patch will be that seen by a red colour-blind person. [This was shown on the screen, and the vermilion, emerald green, ultramarine and gamboge were placed in the mixed light, and the alteration in colour of the pigments noted.] In the same way the white light which, blue and green colour-blind see, can be shown.

In measuring the luminosity of the spectrum you cannot but have noticed that the shadow illuminated by the white light never appeared as white, but always coloured. Thus, when placed in juxtaposition with the yellow, the shadow illuminated by the white light appeared bluish; when with the green, reddish; and when with the blue, yellowish. The colour given to the shadows illuminated by the white light is merely the effect of contrast, and is due to error of judgment by the eye. The tendency of white in proximity to a colour is to make it to appear of the hue of the complementary colour, to which I shall draw attention in my next lecture.

LECTURE III—DELIVERED DECEMBER 10, 1888.

My first business to-night is to show you the third constant of colour. You will recollect I told you that the hue is one constant. the luminosity of colour the second, and that the third is the purity of colour. The purity of colour is that which is perhaps the most difficult to measure, but not so difficult to describe. No colour is pure unless it is unmixed with white light. I propose to show you how you can get colour so impure that eventually the colour will entirely disappear and will leave to your eyes only the impression of white. I think my first experiment will very likely demonstate this.

The apparatus is exactly that which you saw before, viz., the colour-patch apparatus. I am only allowing a small beam of light to come through the prisms, to get a small round patch on the screen, instead of the big white patch square to which you are accustomed. Now, supposing I pass the slit in the card through the spectrum, that patch becomes coloured with any of the colours with which I wish to experiment. The reflected beam gives is a large square of white light, which I superpose over the small coloured patch. Let us see whether we can extinguish that coloured light or not. I may take red, green, or blue, and then if I place the rotating sectors in front of the coloured beam you will see that by making the coloured patch fainter it will entirely disappear. This is the case whether we have a blue, red, or a green patch. That the colour is still present I can demonstrate by cutting off the white light, when you see the colour on the screen.

The lesson I wish to inculcate is this—that the blue, green, and red which you saw disappear, and which were mixed with more and more white light, are essentially impure colours, and most impure where the white light is strongest. It was by this method that originally the luminosity of the spectrum was measured. It was seen how much white light it took to extinguish a colour on a screen, and according to the white light it took, so the luminosity was supposed to be proportional to it. To my mind it is not a very satisfactory way of testing luminosity, and I think the way I showed you in the last lecture is far preferable.

There is another deduction I want to point out with reference to this, which is of importance to artists. In water-colour painting it is well known that in order to get what artists call a certain amount of warmth in the picture, a wash of yellow ochre is very often given to the white paper before it is worked upon. Those of you who are water-colour painters know very well that, although you may appear to have a wash of colour on the paper when it is moist, yet when it is very dry apparently there is nothing but white left behind. The colour is so diluted with white that it does not appear to the eye, but the colour is there all the same, and if you increase but slightly the amount of pigment the colour may be visible. All the colours you place on that apparently white paper mix with the yellow ochre. Remember, then, that if you have a wash of water-colour on a sheet of white paper, and it does not appear to the eye, yet subsequent washes of any colour will bring out that colour, and in the case of yellow ochre will give that warmth which artists so often desire to have upon their sketches.

Now, then, as to the question of diluting one colour with another. We have, so far, only diluted a pure colour with white light; but in diluting one colour with another we enter into a region which has been traversed by a great many experimenters, amongst others by Clerk Maxwell and Lord Rayleigh, and there is an immense amount of interest in the results which have been obtained. Some of them I hope to show you in as simple a manner as I possibly can. But I want you to recollect that one can only touch on the fringe of the subject, as it were, in an hour's lecture.

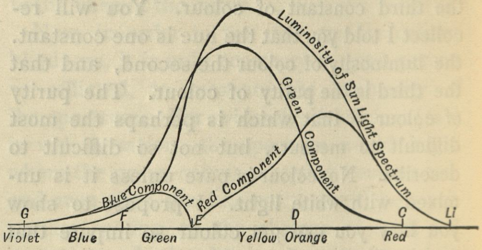
Let me pass some slits through the spectrum of this patch-forming apparatus. First we have a patch of white light, and by a simple means I propose to show you what colours come through the slits placed in the spectrum. If I put another lens L_6, Fig. 1, in front of the big lens, which condenses the spectrum to form the white patch, you will find I can get the

spectrum itself fairly defined upon the same screen as that on which the patch was formed. The second lens in reality produces an image of the first spectrum which was formed in the plane usually occupied by the focussing screen. Now suppose I pass a series of slits through the spectrum you will see the kind of light I am going to use. I have here two colours, and I will show you what is the effect of blending those two—green and red—together; I have only to remove this lens, and we see an orange patch, I will allow another colour to come through a third slit (the card has several), and replacing the small lens we see the three colours. If I blend those three I get a green, and so I may go on blending the colours by passing more slits through the spectrum. Here I have four, and I daresay we shall get a different result again—still it is a green. Perhaps one of the most interesting ways of showing colour mixtures is to take away both lenses, and let different parts of the spectrum pass through the slits, and paint themselves upon the screen. We begin with the red, and here we have a red patch. Then I add yellow which forms orange, and then I shall add a third patch, and pink is formed, then green and blue by adding others until we get nearly a white light in the centre; so I can keep passing these slits through the spectrum, and get many varieties of colour.

Thus we see it is not necessary to have the whole spectrum in order to get certain coloured lights. All we have to do is to take certain portions of the spectrum, and if properly chosen their combination gives us what we call a white light. For example, I wish to show a crucial experiment. I believe every artist will tell you that the combination of blue and yellow gives a green. Now I want to demonstrate that blue and yellow do not give you a green in accordance with the artist's notion, but something totally different. I form my white patch on the screen, as before, and by means of the small lens put a big spectrum on the screen. Passing through the small spectrum two slits, cutting off in the one case all the spectrum except the yellow, and in the other all except the blue, which you see on the screen, and then removing the small lens, in stead of getting green we get white. Thus it requires only two parts of the spectrum to be combined in order to get white. So we see blue and yellow give white, not green. This is a crucial experiment, because on this is based a great deal of the theory of colour mixtures, and I want you to bear that in mind.

I would once more ask you to remember that the eye only appreciates three colour sensations, viz., red, green, blue, and that all the other colours which are seen by the eye are composed of two or more of these three colour sensations. I told you the luminosity of the spectrum was greatest in the green. In the diagram

FIG. 9.



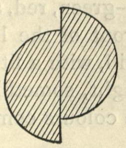
(Fig. 9) we have the luminosity curve on a normal or wave length scale; the maximum luminosity is therefore a little bit more towards the violet end of the spectrum than in the prismatic spectrum; the red component, the green component, and the blue component of the luminosity of white light, are shown in the diagram. These three luminosities together make up the luminosity of the spectrum of white light. The blue, you will notice, has but little luminosity compared with the green and the red. The luminosity in the green is far greater than any of the other two sensations. This I wish to get firmly impressed in your minds, noting that the blue is a much less important colour than green or red; in other words, it is far preferable to be colour-blind to blue light than to green or to red light. This, of course, is founded on Clerk Maxwell's theory, though the curves are derived from our own measurements. I think the researches which General Festing and I have made bear out in a very great measure, although they differ in some respects in detail, the results which Clerk Maxwell himself got.

It may be said that we have been dealing with spectrum colours, and not the colours of every-day life. Is it possible that if you are not dealing with spectrum colours that yet you get the same result? The answer to this question I will give by experiment in a very simple manner, and we shall see that we do get the same result whether we are using the colours of pigments or the pure colours of the spectrum. Recollect there were only two rays combined to form white in the

experiment I showed, whereas in the colour of a pigment you may have a great many colours combined, although they give the sensation of one colour to the eye.

The electric light illuminates a circular aperture, behind which is ground glass, and by a lens I can throw an image of this aperture upon the screen. Instead of a simple lens I have here a lens which is divided into two halves. The centre of one half lens is raised slightly above the other. Now every portion

FIG. 10.



of the lens will give an image by itself, and therefore each half of the lens will give a separate image, one overlapping the other. Thus on the screen we now have two images of the aperture which is in front of the lantern. If I put a piece of yellow glass in front of one half of this lens, I form a yellow disc, and if I put a piece of blue glass in front of the other I form a blue disc, and where the two overlap you have the real colour which a mixture of the blue and yellow lights will give. You can see that yellow and blue do not make green, but white.

But the artist, after all said and done, is not wrong in one way, because he more often than not mixes his pigments together and not the colours reflected from them. Supposing I put the yellow glass in front of the aperture, I then get two yellow discs; if the blue glass be placed in front of the yellow glass, however, I get two green discs.

Now let us see why this is the case. I must come back to my spectrum, to which we have always to refer when we are dealing with colour. I will put the two pieces of glass successively in front of the light passing into the slit, and ask you to notice what happens. With the blue glass a great deal of red is cut off, and a good deal of yellow; the blue is nearly as bright as it was before, and the green is fairly bright. If I substitute a piece of yellow glass for the blue, the blue is cut off, and the green left almost as bright as it was before, and the yellow and red are also left. In the one case, recollect, we had the blue and the green left, and the red and yellow cut off. In the other case we had the blue cut off, and the green and the red left. If we take one from the other we get the green left, so that if I put these two glasses together in front we ought to get only the green left, which is the case. Now if I take away the small lens from the front of the big lens, and form a patch, we have that patch of the same greenwhich you saw in our previous experiment. Here, then, we have the combination of blue and yellow making up the green. Now for one more experiment in relation to this. If a blue sector and a yellow sector be rotated together, and, if what I have said be true, instead of forming green they ought to form grey, *i.e.*, degraded white. Let us see whether it does so. The two discs are now rotating, and we get what is not, at all events, far from grey. Thus we get a blue or a yellow forming a grey or white, when the blue and the yellow are each presented to the eye separately.

Now, I shall have to show you why it is that when they are not presented to the eye separately they form the green. This is a yellow chromate solution in a cell. I place the chromate solution in front of the lantern; the yellow light falls on the blue sector, which is now at rest, and we have a green. The yellow is almost unaffected, but there is no doubt about the blue becoming green. Prussian blue used in a similar manner leaves the blue sector nearly unaltered, but the yellow has now become green. If I take a still darker blue, the green becomes more pronounced than it was before. You recollect I proved to you, or tried to do so, that it did not matter whether a pigment was next to the paper, or away from the paper, so long as it was in front of the source of light. Now in the case before you, when you mix yellow and blue together, as an artist mixes pigments, you have one particle of yellow, say, in front of a particle of blue, and, therefore, the light which passes through the yellow is that which reaches the blue particle, and that they both absorbed I showed you in the spectrum. The yellow absorbed in the blue alone, and the blue absorbed in the yellow and red, green rays would, therefore, only come through the two.

For the same reason, when I held the yellow glass in front of the beam of light, the blue became green, simply because the yellow glass blocked out the blue, and the blue particles on the paper only allowed the green to pass through. This exemplifies

again what I told you, that it does not matter where you have your colouring matter, whether it is miles away from the paper or absolutely in contact with it, so long as it is between the source of light and the paper itself. But artists, whether they do so knowingly or not, employ the method of mixing the light reflected from the pigments, as well as mixing the pigments themselves, of mixture of colour. We know perfectly well that gamboge and cyanine blue are a very favourite mixture for greens; but, on the other hand, you will find that in some of the most beautiful works of art broad washes, to obtain light and shadow, are not adhered to, but, as in the execution of portraits, stippling is resorted to. Now stippling means that different colours in fine dots are placed close to one another, so close that the eye cannot separate them, and the colours blend one into the other. Thus, if you have, for instance, a great many yellow (gamboge) dots distributed amongst a great many blue (cyanine) dots, the result is exactly the same as you saw on the screen, viz., instead of getting a green the general effect is a grey. This is the whole principle on which stippling depends, viz., the juxtaposition of very different colours to give an effect which otherwise cannot be obtained. Now, the explanation may be new or it may be old, but from having examined a large number of stippled water-colour drawings, one can only come to the conclusion that many of the tender greys which are often seen in stippled works are simply due to the fact that you have two or more colours in dots and fine lines in juxtaposition one to another, which colours, when combined in a rotating apparatus such as you have seen, give the effect of grey to the eye.

I must now repeat the experiment with which I began my series of lectures, viz., that the three colours, vermilion, emerald green, and ultramarine blue, will give you white; and I think that this will be a proof—at all events, a minor proof—that the three sensations which the eye distinguishes are green, blue, and red, and not yellow, blue, and red, as used to be held. Here we have three colours rapidly rotating, and those three brilliant colours give the sensation of white. What proof is there in this that the three primary colours are red, blue, and green? Recollect that I showed you just now that blue and yellow made white, therefore red and green must make yellow. Is that the case? If that be the case, I think the point is proved. Let us see whether such is the case. We will go back to our apparatus consisting of the half-lenses. There is a reddish glass in front of one half-lens, green in front of the other half, the part of the discs which overlap is yellow; hence red and green make yellow. We have already seen that blue and yellow make white, but it takes red, green, and blue to make white; therefore yellow is equal to red *plus* green.

Let me further show this. I have a lens in front of the lantern which forms a slightly larger image of the aperture than before. Cemented alongside one another I have three coloured glasses—green, red, and blue. These, when placed in front of the lens, and in close contact with it, will, with a little manipulation, show a disc of light, something approaching white. The three colours combine to give this result.

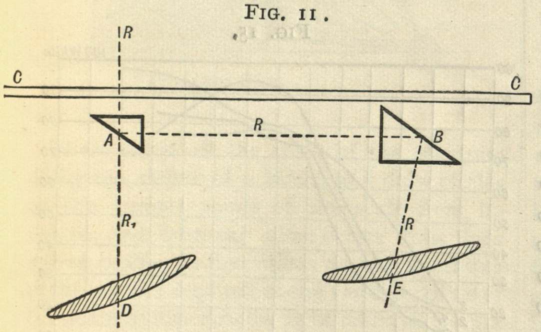
I am next going to show you how we can get complementary colours. A patch of white light is now upon the screen by means of our much used apparatus. I have a card in which is cut a wide slot to allow the whole spectrum to pass through, and suspended from it is a little prism, which will cut off a certain amount of the spectrum. The part so cut off will be reflected on to a mirror, and by means of a lens will form a patch on the screen. The rest of the spectrum will go through to the usual lens, and form another patch of white minus the colour reflected. The two patches when superposed give white, but a rod placed in the front give two complementary colours side by side. The complementary colour is that which with the colour itself will give white. I will cut off the different parts of the spectrum, and you will see the real complementary colour. On cutting out the different colours you will notice I get almost every variety of hue, and the colours complementary to them. This seems a very simple way of getting complementary colours, and I think it is instructive, as at the same time it is seen that the background, where the two overlap, is white.

The next point we come to is one that is very germane to our subject, and that is how are we to measure the intensity of pigments in any satisfactory way? As far as I know, a paper which General Festing and I recently read before the Royal Society explains the only method which has been satisfactory, so far, and I hope to show you how that is done.

The desideratum is to compare the intensity of any colour of the spectrum which is reflected from any pigment with that which is reflected

from a surface of white paper. When you get that you know exactly the colour value of the pigment, and by certain methods which I shall show you bye-and-bye, you can at any time make upon the screen by the spectrum alone the exact colour of the pigment you have measured. In order to take these measurements it is necessary to have two similar spectra one above the other, and this we get in the following manner. Upon the screen a lens forms an image of an aperture placed in front of the lantern. Where the rays passing through the lens cross, I put what is known as a double-image prism, and by it we get two discs of light, which will rotate round a centre as the prism is turned round its axis. This double-image prism is of Iceland spar, made by Mr.

FIG. 11.

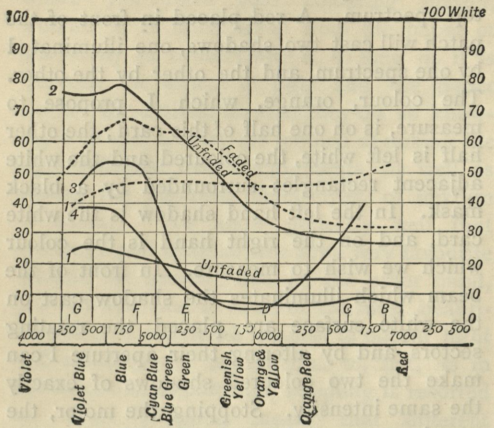


Hilger with his usual ability. It gives us the means of at once getting two spectra one above the other having exactly the same quality of light.

In contact with the lens of the collimator, as it is called (which makes the rays which strike the prism parallel), is placed the double image prism; we thus get two sets of parallel rays, one set inclined at a slight angle to the other. Two spectra by this artifice are formed by the prisms, one above the other, and separated by a breadth of about one-eighth of an inch. Passing a slit through those two spectra, the same colour is cut off from each when the double image prism is properly in adjustment. To the card, C, in which the slit is cut, two right-angle prisms are attached, as shown, and so adjusted that the beam, R, from the top spectrum is reflected first by the prism A, and then by the prism B, on to the screen. A lens, F, of about two feet focus, in front of B, makes a coloured patch on the screen, overlapping a patch of the same colour formed by the lens D, which comes from the bottom spectrum. By this means we get a parallax of lights of exactly the same colour, one from the bottom spectrum, and the other from the top spectrum. A rod placed in front of the patch will cast two shadows, one illuminated by one spectrum, and the other by the other. The colour, orange, which I propose to measure, is on one half of this card; the other half is left white, the coloured and the white adjacent rectangles surrounded by a black mask. In the left hand shadow is the white card, and on the right hand is the colour which we wish to measure. In front of the beam which illuminates the shadow cast on the white surface are placed the rotating sectors, and by altering their aperture I can make the two coloured shadows of exactly the same intensity. Stopping the motor, the angular aperture is read off. With another part of the spectrum exactly the same thing is done; by that means we are able to compare the amount of light which is reflected for the pigment, and from the white card.

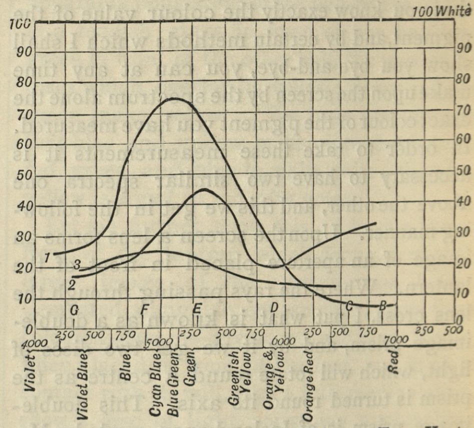
It is on this principle that these particular colours were measured. To graphically show their reflective power for different parts of the spectrum, the following plan was adopted. Suppose, for instance, that for one spectrum to match the other in intensity throughout its length required an angular aperture of 100, and if for emerald green at a wave length of (say) 5,500, it required an angular aperture of 45, then in forming this curve we set off the wave lengths as a base line, and at 5,500 set up this angular aperture, which gives us a point on the curve, whilst the light reflected from the white surface is represented by 100. Thus, at this point, emerald green reflects only $\frac{45}{100}$ths of this particular light. By taking numerous other parts of the spectrum you are able to build up a curve, which is an absolute measure of the light reflected from the pigment, as compared with that reflected from the white surface. I want you to notice how very peculiar are the curves of the yellow pigments. There seems to be very little difference in the intensity of light reflected from them, but to the eye they appear of decidedly different hues. It is just these little differences in the curves which make up the difference in the hues which are so noticeable. Again, I want you to notice cobalt. You see what a large proportion of red there is in cobalt, and what a little red there is in Prussian blue, Antwerp blue, indigo, or French ultramarine. If we take a line tangential to the bottom of these curves, and parallel to the base line, the height of this tangent shows the amount of white light which

FIG. 12.



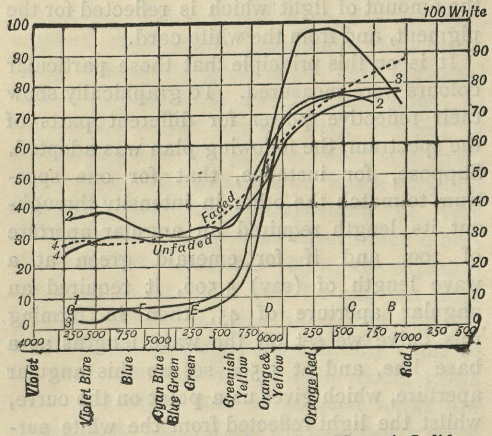
1. Indigo. 2. Antwerp Blue. 3. Cobalt.
4. French Ultramarine.

FIG. 13.



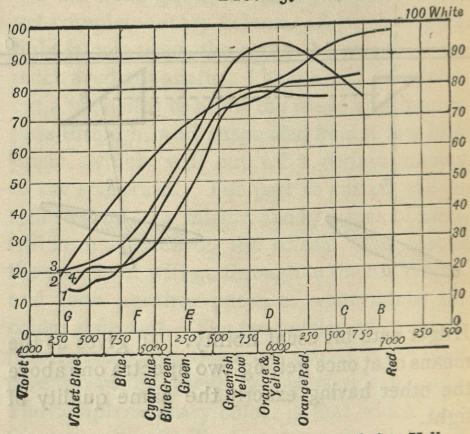
1. Emerald Green. 2. Chromous Oxide. 3. Terre Verte.

FIG. 14.



1. Vermilion. 2. Carmine. 3. Mercuric Iodide.
4. Indian Red.

FIG. 15.



1. Gamboge. 2. Indian Yellow. 3. Cadmium Yellow.
4. Yellow Ochre.

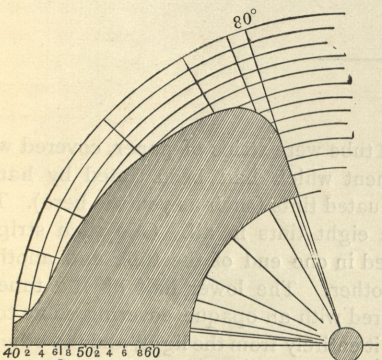
is reflected from the pigment, and is a measure of its impurity. For instance, if you take the curve of cobalt, you will see it has about 3 per cent. of white light mixed with it; whilst in the tint measured of Antwerp blue there is about 23 per cent. of white light mixed with the true colour of that pigment. You will notice that, in all cases, a certain amount of white light is reflected from the pigments, and therefore not one is really a pure colour.

Now I want to show you another method, and one which has never been exhibited before, by which we can obtain the intensity of colours in a very simple way. I use for convenience sake a rather short focussed lens in the camera, as I want to form rather bigger patches of monochromatic light. Behind those black discs of the motor is a disc of white card, and I am going to measure the intensity of spectrum colour reflected from a coloured disc by a novel method. I can put any coloured disc I like in front of the sectors, and in contact with them. I rotate the sectors in the coloured patch, and I can alter the amount of white on the larger disc until I get it to match the luminosity of the colour in the centre. Knowing how much black has to be mixed with white, in order to bring the tint reflected from the colour in the centre to the same value as that reflected from the rotating black and white, I can readily determine the intensity of the light reflected. (Several colours were measured in succession, in the manner described.)

Next on my programme is the method of producing on the screen the exact colour of any pigment. The researches of Dr. Russell and myself on various pigments which have faded in light would be of little value, unless in, say, a thousand years' time those colours could be reproduced with the same accuracy

with which they were measured. We have a means by which we can, without having the pigment itself, absolutely reproduce that colour from a card such as this. I will show you on the screen how it is done.

FIG. 16.



Prussian Blue

If we mark off the scale of the spectrum along the radius of a circle, and draw circles at the various points of the scale from its centre, and from the same centre draw lines corresponding to the various angular apertures of the sectors required at the various points of the scale to measure the light reflected from a pigment, the point where one of these lines cuts the circle drawn through the particular point of the scale to which the aperture has reference, gives us a point on a curved figure. Such a figure, when rotated in front of the spectrum in the proper position, will cut off exactly the right amount of the spectrum at each part of it to give the colour required. I will show you one or two of these colours, and by that means you will see that we have literally templates by which our successors in science will be able to reproduce the colours which we have measured in our experiments, and to see whether any alteration has taken place in those particular pigments we have used, and which we propose to leave, either at the South Kensington Museum or elsewhere, for the benefit of those who come after us. (The colours of various pigments of blue sky, gold, and gaslight, were reproduced on the screen.)

By cutting out templates like these, and in your laboratory carefully making the necessary adjustments, you can always reproduce on the screen any colour you may have measured, and if you use the light in which the colour has to be viewed, be it sunlight, gaslight, starlight — whatever light it is—to form the spectrum, you will get on the screen the colour as it would be seen in that light.

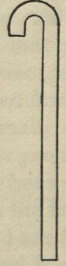
LECTURE IV.—DELIVERED DECEMBER 17, 1888.

We have, in the three preceding lectures, seen how colour is produced, and how it depends on three factors—the kind of light falling on to the substance, the kind of substance itself, and also the eye of the observer.

To-night I have to endeavour to explain in one hour what ought to take many more hours, how light acts in altering the colour of pigments through what I may call mechanical means. A water-colour picture (I shall deal only with such) is exposed in the ordinary atmosphere of a room. Sometimes that room is without a fire; consequently the atmosphere becomes more or less damp, and all absorbent objects, such as paper, take up moisture. At other times, when there is a certain amount of warmth, the moisture which it would take from the air is less; so that a picture is exposed to alternations of damp and dryness. Dr. Russell and myself concluded that it would be quite fair for testing the stability of water-colour pigments if we exposed them to the ordinary outside atmosphere, and then traced the amount of fading which took place, remembering this, that a picture inside a room would certainly be more stable, supposing moisture had anything to do with fading.

We prepared tubes, as in Fig. 17, perfectly

FIG. 17.



open at each end, but with a small cork in the unbent end, the cork being pierced with a large hole. A current of air could pass throughout the tube when hung on a bar by the bend and exposed to the sunlight. Inside each tube were strips of paper, covered with a pigment which had been tinted by hand in graduated tints (such as you see here). There were eight tints in all. One such strip was placed in one end of the tube and another in the other. The lower half of the tube was covered with an opaque covering so as to protect it entirely from the light, and the other was left free to the sunlight and the light from the sky. By-and-by I shall show you why it was we deliberately chose sunlight to which to expose our water colours. From theoretical considerations we arrived at the conclusion that fading would take place in a shorter time in sunlight than it would do if we exposed it to the open sky alone.

In such a series of tubes, containing in all somewhere about 100 colours—39 being simple colours, the others being mixed colours—were exposed. The first reading of the amount of fading was taken in August, 1886, or after four months' exposure, and we found that in many of the colours fading had taken place to a certain extent, although perhaps not to so large an extent as might have been anticipated. From time to time after that date the tubes were examined, and the amount of fade ing noted, our notes showing the deepest tint which was visibly acted upon. Finally, we were obliged to conclude our experiments, owing to the impatience of certain gentlemen who were anxious to get the results we had obtained, apparently for their own advantage rather than for that of the public. We thus stopped our first series of experiments in March of this year, or after these tubes had been exposed about one year and nine months outside my laboratory at South Kensington.

In these tubes, then, we had the ordinary atmosphere, to which moisture and air had free access. If the tube got the least bit heated a current passed through it, much in the same way as would be the case in a chimney. The great point to settle was whether the fading which we knew must take place,

and which we subsequently noted, was due to the air itself, or to the air *plus* moisture, or to the moisture alone. In order to test that, we passed air over various drying materials, dried the papers and tubes very thoroughly. The papers were then placed in straight tubes sealed at one end, and when filled with dry air the other end was sealed off, and they were exposed to sunlight, one paper being shaded from it as before. In the case of the open tubes, we found out of 39 simple colours only 12 were not acted upon; and in Table I. you have the 39 single colours in the order of their fugitiveness.

TABLE I.

Carmine.	Permanent blue.	
Crimson lake.	Antwerp blue.	
Purple madder.	Madder lake.	
Scarlet lake.	Vermilion.	
Payne's grey.	Emerald green.	
Naples yellow.	Burnt umber.	
Olive green.		
Indigo.		
Brown madder.	Yellow ochre.	
Gamboge.	Indian red.	
Vandyke brown.	Venetian red.	
Brown pink.	Burnt sienna.	
Indian yellow.	Chrome yellow.	
Cadmium yellow	Lemon yellow.	
Leitches blue.	Raw sienna.	Show no change.
Violet carmine.	Terre verte	
Purple carmine.	Chromium oxide.	
Violet carmine.	Prussian blue.	
Purple carmine.	Cobalt.	
Sepia.	French blue.	
Aureolin.	Ultramarine ash.	
Rose madder		

Vermilion is ordinarily supposed not to change at all, but, as a matter of fact, it does change, and in every sample there has been a little blackening. Those last on the list, yellow ochre, Indian red, and so on, show no change whatever after being exposed to as much sunlight as there was in one year and nine months. They remained perfectly unaltered, and, if you begin with rose madder (all below which may be said to be practically permanent) you have a very good gamut on which an artist could work in water colour.

In the closed tubes with dry air, out of thirty-eight sample colours which were exposed, twenty-two were not acted upon, so that it is evident that moisture had something to do with the fading of some.

TABLE II.

Name of Colour.	Dry Air.
Carmine	Faded to 7.
Crimson lake	Gone to 5.
Scarlet lake	Faded and darkened.
Vermilion	Gone black.
Rose madder	No change.
Madder lake	No change.
Indian red	No change.
Venetian red	No change.
Brown madder	Faded to 4.
Burnt sienna	No change.
Gamboge	Faded to 3.
Aureolin	No change.
Chrome yellow	No change.
Cadmium yellow	No change.
Yellow ochre	No change.
Naples yellow	No change.
Indian yellow	Faded to 4.
Raw sienna	No change.
Emerald green	No change.
Terre verte	No change.
Chrom. oxide	No change.
Olive green	No change.
Antwerp blue	Faded to 3.
Prussian blue	Faded to 5.
Indigo blue	Faded to 7.
Cobalt blue	No change.
French blue	No change.
Ultramarine ash	No change.
Leitches blue	Faded to 5.
Permanent blue	No change.
Payne's grey	No change.
Violet carmine	Faded and brown.
Purple carmine	Faded.
Purple madder	Faded to 4.
Sepia	No change.
Vandyke brown	V. sl. faded.
Burnt umber	No change.
Brown pink	Faded to 4.

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

The next series was interesting. The same kind of tube was taken and filled with hydrogen, and also with as much moisture as the hydrogen and paper would take up. The tubes were then sealed and exposed to light approximately for the same length of time as the other tubes. As a matter of fact, out of thirty-six colours twenty-two remained unchanged, the same as before. Hydrogen, I may say, is practically an inert gas for this purpose, as we proved subsequently.

Then we come to the most interesting series of all, when we excluded air and moisture from the water colours. We took exactly similar tubes, dried the papers very carefully indeed, dried the tube, inserted the papers, put a

Sprengel pump to work, and made a vacuum, and then when the vacuum was very complete, sealed off the top and exposed them.

TABLE III.

Name of Colour.	Vacuum.
Carmine	No change.
Crimson lake	No change.
Scarlet lake	No change.
Vermilion	Gone black.
Rose madder	No change.
Madder lake	No change.
Indian red	No change.
Venetian red	No change.
Brown madder	No change.
Burnt sienna	No change.
Gamboge	No change.
Aureolin	No change.
Chrome yellow	No change.
Cadmium yellow	No change.
Yellow ochre	No change.
Lemon yellow	No change.
Naples yellow	No change.
Indian yellow	No change.
Raw sienna	Sl. darkened.
Emerald green	No change.
Terre verte	No change.
Chrom. oxide	No change.
Olive green	No change.
Antwerp blue	No change.
Prussian blue	V. sl. faded.
Indigo blue	No change.
Cobalt blue	No change.
French blue	No change.
Ultramarine ash	No change.
Leitches blue	No change.
Permanent blue	No change.
Payne's grey	No change.
Violet carmine	Sl. darkened.
Purple carmine	Sl. darkened.
Purple madder	V. sl. gone.
Sepia	Sl. faded to 6.
Vandyke brown	No change.
Burnt umber	No change.
Brown pink	No change.
Indian yellow and rose madder	No change.
Rose madder and raw sienna	No change.
Raw sienna and Venetian red	No change.
Vermilion and chrome yellow	More yellow.
Burnt sienna and Naples yellow	V. sl. faded.
Indigo, Indian yellow, raw and burnt sienna	No change.
Indigo and gamboge	Gone blue.
Prussian blue and gamboge	Gone green.
Burnt sienna and Antwerp blue	Gone red.
Raw sienna and Antwerp blue	Gone brown.
Prussian blue, raw and burnt sienna, and Indian yellow	Gone brown.
Prussian blue and burnt sienna	Gone brown.
Indigo and Vandyke brown	Faded.
Prussian blue and burnt sienna	Gone brown.
Prussian blue and raw sienna	Gone red.
Indigo and raw sienna	No change.
Indigo and burnt sienna	No change.
Indigo, raw and burnt sienna	No change.
Prussian blue and Vandyke brown	Gone brown.
Indigo and Venetian red	No change.
Prussian blue and Indian red	Gone red.
Indigo and Indian red	No change.
Prussian blue and crimson lake	Gone pink.
Antwerp blue and crimson lake	Gone pink.
Indigo, Venetian red, yellow ochre	No change.
Prussian blue, yellow ochre, Venetian red	Gone red.

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

We here arrived at the very interesting fact that out of thirty-nine simple colours which were exposed, only five were acted upon in the very least, and the amount of change was so slight that you might almost say every colour remained perfectly unchanged in vacuo. The five that were changed were vermilion (which went black to a very slight extent), raw sienna, Prussian blue, purple madder, and sepia. We are apt to look on sepia as one of the most permanent pigments; as a matter of fact it is fugitive in ordinary air, and those who have examined sepia drawings made in the early part of the century will see there has been certainly a distinct fading of those drawings. By the process of exhaustion, we arrived at the fact that it requires both moisture and air to cause the fading of these pigments.

Now the question arose—Would heat without light cause the fading of pigments? Where they were exposed to sunlight it might be surmised, perhaps fairly, that in the sunlight, which we know has a heating effect, the fading might be due to this cause in the open tubes.

This could not be the case in the closed tubes, as in them the colours did not fade. To test the action of heat alone, we took tubes in which the papers were sealed up with moist air, and exposed them for three or four weeks, at the temperature of boiling water, in the dark. There was a certain amount of fading in these colours, but I need scarcely say that the fading was small, and also that the temperature to which they were exposed was something far beyond that to which colours in our open tubes were subjected. If you put a thermometer up one of the open tubes when it is in full sunshine, the difference between the temperature of the air inside it and the air outside only varied between

three and four degrees. That was simply due to the fact that there was a draft created up the tube, as already pointed out.

But another point, and a very fair point for the critics to take hold of, is this. It is all very well to say light alone causes fading, but how about light and heat together, would not the heat aid the light? This possible criticism was combated, I hope, in a successful way. A certain series of pigments, washed on paper, were taken and exposed on a vessel containing boiling water; similar papers were exposed to the sunlight free, that is to say, without the presence of the boiling water. In some few cases the fading was rather more rapid, in others less, and you will very readily see why, in some cases it was rather less rapid. You require moisture *plus* air in order to cause fading, and if you heat the paper of course you take away part of the moisture—one of the agencies which are conducive to fading. But the difference between those exposed on boiling water, and those exposed without, was so small that you might take the action of light *plus* heat as equivalent to the action of light alone.

There was another experiment we had to try, and that was as to the rays which caused the fading. I have shown you in my previous lectures that beautiful band of colour we call the spectrum. I daresay you noticed that the beam of light which passes through the slit to form the spectrum is uncommonly narrow; for accurate experiments we should not use it more than 1-1000th inch wide, and that has to be spread out into that band of colours, so that really the light which strikes upon the screen is very feeble indeed. If we had attempted to expose some of these pigments in the spectrum, we should have had to expose them for some thousands of years, and as life is shorter than this, we thought it was better to take some other means of arriving at the conclusion as to what coloured rays were the active agents; so we adopted a method which, perhaps, may be called crude, but I do not think it is crude when you know how you are going to work. We exposed slips of paper beneath coloured glass—red, blue, and green, and also white. Here are some of the pigments which were actually exposed. We got the results as shown in Table IV. (p. 20).

We exposed 39 or 40 simple colours besides compound colours, and I want you to notice how very few faded in the green, in the red less than the green, but a very great many more under the blue glass than under either of the other two. You will see that the blue and the white were almost equally effective. Had a certain proportion of the blue rays in the white light been cut off by the glass, practically those two columns, white and blue, would have been identical. Under the red and green glasses the fading of the few pigments which succumbed was so small that it required a practised eye to distinguish it.

Now I will read you some conclusions we came to with regard to the fading of water colours:—" Mineral colours are far more stable than vegetable colours, and amongst those colours which have remained unaltered, or have very slightly changed after an exposure to light of extreme severity, a good gamut is available to the water - colour artist. The presence of moisture and oxygen are in most cases essential for a change to be effected, even in the vegetable colours. The exclusion of moisture and oxygen, particularly when the latter is in its active condition, as experiments to be described in our next report show, would give a much longer life even to these than they enjoy when freely exposed to the atmosphere of a room. It may be said that every pigment is permanent when exposed to light in *vacuo*, and this indicates the direction in which experiments should be made for the preservation of water-colour drawings. The effect of light on a mixture of colours which have no direct chemical action on one another is that the unstable colour disappears, and leaves the stable colour unaltered appreciably. Our experiments also show that the rays which produce by far the greatest change in a pigment are the blue and violet components of white light, and that these, for equal illumination, predominate in light from the sky, whilst they are less in sunlight and in diffused cloud light, and are present in comparatively small proportion in the artificial lights usually employed in lighting a room or gallery."

Now, it has been said that moisture and oxygen are essential for the fading of water-colour pigments. Is it possible that they can fade without light? I have here a stream of oxygen passing through this tube in which are some papers coated with pigments; half of each paper has been damped and the other half is dry. In connection with this tube is an ozone generator, and a Ruhmkorff coil produces ozone, or the active state of oxygen, which is said to be particularly present near the sea. In this

TABLE IV.

	White.	Blue.	Green.	Red.
Purple Madder	Faded to 2	Faded to 1	—	—
Antwerp Blue	No experiment	Faded	—	—
Leitches Blue	Sl. faded	Sl. faded	Darkened	Darkened
Violet Carmine	Faded to 1	Faded to 1	—	—
Payne's Grey	Faded to 1	Bluer	Blue	—
Indigo	No experiment	Faded to 1	—	Sl. faded.
Prussian Blue	No experiment	Sl. faded	—	V. sl. faded.
Rose Madder (2 experiments.)	Sl. bleached	Sl. faded	—	—
Brown Pink	No experiment	Faded to 3	—	—
Crimson Lake	No experiment	Faded	Sl. faded	Sl. faded.
Vandyke Brown	No experiment	Faded to 1	Sl. faded	—
Vermilion	Darkened	V. sl. darkened	—	—
Carmine	No experiment	Faded to 3	Sl. faded	—
Gamboge	No experiment	Faded to 1	—	—
Indian Yellow	No experiment	No change	—	—
Sepia	Become lighter	Become lighter	—	—
Burnt Sienna	No change	No change	—	—
COLOURS MIXED WITH CHINESE WHITE.				
Antwerp Blue	No experiment	Bleached	—	—
Prussian Blue	No experiment	Bleached	—	—
Purple Madder	Bleached	Bleached	—	—
Burnt Sienna	No change	No change	—	—
Gamboge	No experiment	Sl. bleached	—	—
Indian Yellow	No experiment	Sl. bleached	—	—
Vandyke Brown	No experiment	Bleached	—	—
Brown Pink	No experiment	Bleached to 3	—	—
Crimson Lake	No experiment	Bleached to 3	—	Sl. faded.
Carmine	No experiment	Bleached to 3	—	—
Vermilion	Blackened	Blackened under 1 and 2	—	—
Rose Madder	Sl. bleached	V. sl. bleached	—	—
Violet Carmine	Bleached to No. 1 and darkened to 2 and 3	Same as under white glass	—	—
Payne's Grey	Bleached to 1	Become bluer	Become bluer	—
Sepia	Lighter	Lighter	—	—

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

frame [shown] you have a series of colours which have been exposed to moist ozone. A great many are bleached entirely, thus proving, if you have ozone and moisture together, you get a bleaching without the presence of light at all. Here are some papers which were exposed, I think for about ten minutes, to moist ozone before the lecture, and you will be able to see the amount of fading that has taken place. In the example of indigo the bottom part was damped and the top part left dry; the first half has faded, the other has not. In carmine, too, you will see that where it has been damped the colour has entirely gone; the dry part is much less changed. We come then to the conclusion that oxygen and moisture are sufficient for the fading of water-colour pigments, and that it is not absolutely necessary that there should be light present in order tha this fading may take place. Now, as before said, you are supposed to have more ozone at the seaside than inland. It is therefore a matter for consideration whether i't may not be the fact that water-colour drawings fade more rapidly near the sea, where there is more ozone present, than they would do inland. That is a question I am not going to touch upon now, but when we make a subsequent report no doubt that will be brought forward prominently.

We have seen the results of light, and I wish to show you how it is that light acts upon matter. Matter is formed by molecules, or very minute particles, far beyond the vision of the best microscope that was ever made; you can only reason and argue about them from the circumstantial evidence which nature from time to time puts before us. The molecules themselves are composed of atoms. Thus, in the molecule of water it is supposed there are two atoms of hydrogen and one of oxygen. Each molecule is presumably of identical shape, and size, and composition. There has been a certain amount of evidence brought forward that perhaps some molecules of the same kind of matter are rather bigger than others, but to my mind such evidence is incomplete, and I cannot accept it. At any rate, as a rule, we may take it that the size of the molecule is the same for the same species of matter; that, for instance, all water molecules are the same size and composition, as are those which go to form the molecules of these pigments we are considering.

I want to give you a homely notion of what a molecule is like, and how we may suppose the atoms vibrate. I have here a little cell of water, through which a vertical beam of light can be thrown, and again be deflected to the screen. A lens forms an image of the surface of the water on the screen. Around this cell of water I can cause a current of electricity to pass through a coil of wire. When you have a current passing there is a certain amount of magnetism produced which repels magnetism of the like kind. I have here some little needles which are magnetised, and inserted in small bits of cork by one end, the same poles being in the corks. The corks will float on the surface of the water, thus supporting the needles. Now, if we float some of these little magnets in the water, they will repel each other and tend to go farther apart, the reason being that magnetism of the same kind repels. Now if I turn on the current in the wire passing round the cell you will see that they are found to approach one another, and as I move the wire up and down, they alternately approach to and recede from one another.

You must recollect that at the same time that these atoms are vibrating one towards the other, the molecules themselves are vibrating to and fro from one another, so that we have vibrations of the molecule and vibrations of the atom. Now I have told you that the waves of light vary in length; the red waves are the longest, and the blue waves are the shortest, and as they all travel at the same speed, the time of oscillation of the red wave is longer than the time of oscillation of the blue wave. We may take it that the oscillation of a molecule is slower than that of an atom, and it is much more likely to be isochronous with a wave of red light than it would be with one of blue light. Similarly, the waves of blue light are much more likely to be isochronous with the time of oscillation of the atoms than the molecules, and, as a matter of fact, such we find to be the case.

Now let me give you another homely example of what we mean by oscillation on the part of an atom or a molecule. You can quite understand, I think, that if you have a body oscillating to and fro from another body, both of which attract one another, if you increase the oscillation, a time comes when the attraction between the two is so small that there is a great tendency for them to fall apart. If there is another body at hand which is willing to take up one of those atoms—which has a great affection for such atom—it will take hold of it, and bring it to itself. The bob of this pen-

dulum, which is of iron, is supposed to be an atom swinging to and from another atom, and some three inches behind it is fixed a magnet. By puffing with my breath at the same rate as the pendulum vibrates I can increase the amplitude of that oscillation to such an extent that, eventually, the attraction of the magnet for the bob of the pendulum is greater than the force of gravity, and it reaches the magnet and is held by it. This very simple experiment teaches us a lesson. Here we have an atom swinging away, we will suppose, from another atom of something. My breath timing itself with the swing may be taken as the oscillation of the waves of a ray of light. The waves of light perpetually beating on the atom will increase the amplitude of swing of that atom so greatly that if there is another body near it which will take up the atom, it leaves the original atom for it. When such a re-arrangement of atoms takes place, we say that a chemical action has taken place, that is, that light is able to decompose a molecule by robbing it of some of its atoms, and giving them to another body. We get, then, by the decomposition new molecules formed, and consequently new matter, and such a new body may be in the shape of a faded pigment.

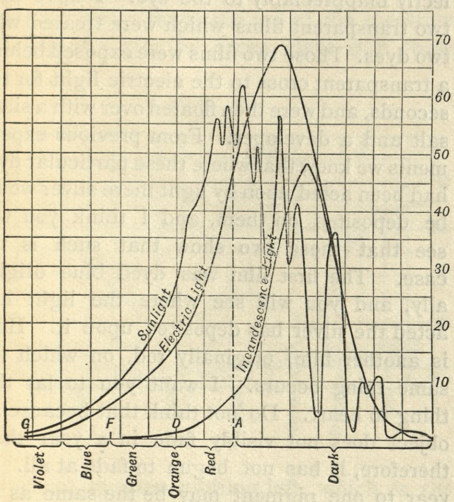
Throwing a spectrum on the screen, I put a layer of pigment in front of the slit, the light passes through it, and we get, as you saw by previous experiments, some colour taken away from the white light, and other colours left behind. In the case before us the red and the green and the blue are left, but most of the green is cut off. I will put another substance (permanganate of potash) in front, which gives a beautiful absorption spectrum, and there are a number of dark bands in it. If I take the iron salt which I used in the experiment in measuring the quantity of light which came to galleries of South Kensington, you see that it cuts off the blue almost entirely. You can see, then, that these various solutions cut off a certain amount of colour from the spectrum. Now the question is this, what becomes of the rays that are cut off? The whole principle of the chemical action, and the heating effect of light upon pigments, is answered by the answer to that question. It is this. Where you have an absorption of light, there you have work done upon the body on which it falls. In that permanganate of potash, for instance, which you saw gave a fine spectrum—the rays missing, which gave the black spaces, were doing work on it. They were heating up the permanganate of potash, or chemically changing it into something else. You cannot have work done on any body unless there is absorption by that body. You understand what I mean by absorption—the cutting off the light by the body. When there is chemical action taking place, the work done is the swinging the atoms away from each other, when heating effect takes place the molecules are swung further apart from one another. I hope I have made clear to you that my view is that when you have chemical action taking place, the absorption takes place in the atoms; when it is a heating effect which takes place, it is the molecules which are acted upon, and made to jostle each other more vigorously. As far as chemical action is concerned we have a very familiar example in photography. I am going to develop a spectrum for you. This has been done before in this room by myself, but as there are many here who have not seen the experiment, I think it might be as well to repeat it. [The photograph of the spectrum was developed.] The paper was covered with bromide of silver, and if I place a slab of bromide of silver in front of the slit, you will see that the absorption exactly agrees with the locality where chemical action has taken place.

Now I have another experiment to show you, and that is the heating effect of radiation. I have here a little instrument called a thermopile which consists of strips of two metals soldered together at one end. If the junction be heated, a current of electricity will pass through wires attached to the other ends when joined; and if a galvanometer is in the circuit the galvanometer needle will be deflected. By means of a mirror attached to the needle, which will reflect the light from a lamp on to a scale behind, I can show you the deflection. I now form a very small spectrum, and cause different parts of the spectrum to fall on the junction of the metals. The needle deflects very slightly with the blue, showing that the heating effect is small; as it gets towards the green and travels into the yellow the deflection is greater, and when we get into the red portion it is again more. At the very limit of the red the deflection is greater still, and outside this colour and in apparent darkness we see that the light on the scale travels further still, showing an increased heating effect. Thus an invisible part of the spectrum which lies beyond the red heats this junction of the two metals more than any part of the visible spectrum. We have here a proof that not only the rays which cause the sensation

of light have a heating effect, but that we also have a heating effect due to dark rays which are not visible.

We have also had proof that light is capable of causing chemical action, and also that it is capable of heating a body on which it falls. If light acts only on the molecules it heats the body; if it swings the atoms further apart, the probability is that there is a chemical decomposition taking place. Those dark rays might possibly have had a chemical action on these pigments which were exposed in our tubes, but it was not probable. You see now the reason why we made experiments with light *plus* heat. I told you we exposed the pigments on paper against a vessel of boiling water to see whether the decomposition was accelerated. It was possible that these dark rays might have heated up the paper to such an extent that the heating action aided chemical decomposition by the blue rays which we found most effective.

FIG. 18.



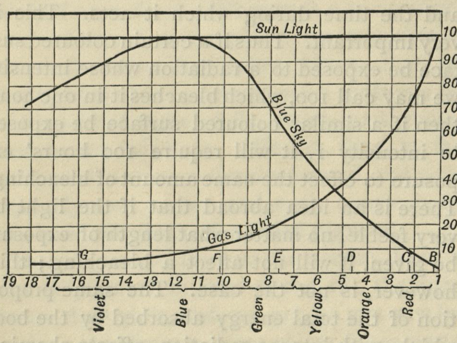
Now I want to call your attention for a minute to this diagram (Fig. 18), which represents the heating effect of different sources of light. The height of the curve is a measure of the heating effect. The curves on the right hand of the dotted line show the energy of the dark rays, whilst on the left the heating effect of the visible spectrum is shown. The heating effect (which is a measure of the energy) of the dark rays is very much greater than the heating effect of the rays which lie in the visible part of the spectrum. I want to call attention to the solar curve; you see what a peculiar jagged curve it has. The jagged indentations mean that some of the visible and dark rays of the sun, during their penetration through our atmosphere, are partially cut off by something, that something being water. These rays are absorbed by the water particles, and vapourise them. The vapour on being chilled again, condenses into clouds, and so we have a constant succession of aqueous vapour and clouds. I also want you to notice the enormous disproportion there is in the energy of the dark rays to visible rays in the incandescence light, as compared with sunlight. You see the incandescence light has very little heating effect in the visible spectrum, and a very large effect in the dark part of the spectrum. The same applies to gas-light and candle-light.

In estimating the chemical action of radiation on a body, there are two factors to be considered, the intensity of the radiation acting, and the time during which it acts. This is very important. Thus if a certain coloured surface be exposed to a radiation whose intensity we may call 100, which bleaches it in one hour, then if a similar coloured surface be exposed to intensity 1, it will require 100 hours' exposure to effect the same amount of bleaching. There is an idea abroad that if the light be very feeble, no matter what length of exposure be given, it will not affect a bleaching; this, however, is not the case. The same proportion of the total energy absorbed by the body which, with intense radiation, effects chemical decomposition, on exposure to feeble radiation is doing the same kind of work. We may say, briefly, that the deductions from scientific experiments lead us to believe that if strong light causes fading, a feeble light will do the same, if the exposure to it be prolonged. The pendulum experiment, I think, fully illustrates what I mean. I will give you a rather fuller illustration, however. The amount of increased swing that light can give to the atom means an increase in the amplitude of a wave, and the amplitude of a wave in the sea is the height from the crest to the trough. Suppose we have a heavy church bell hung without friction on its supports, and without any resistance to its motion, and suppose it to make a complete swing once a second. Suppose also that at the end of the bell-rope there was a small horizontal plate, and at intervals of a second a thousand grains of water fell from a fixed height on the plate. The bell would gradually oscillate; the bell would be like this pendulum, and finally it would oscillate so greatly that the bell would ring. Now, if instead of 1,000 grains falling from the same height, we had

but one grain falling every second, it would take 1,000 times longer before the bell rung; or if the weight were 1-1000th of a grain, it would take one million times as long before it rung. The work done by the dropping water may be looked upon as the work done by the amplitude of the wave of light on the atom, as it, too, moves without friction and without resistance.

As to the light which pigments in water-colour drawings are ordinarily exposed, a few remarks may be made. There is no doubt that pictures as a rule are carefully protected from direct sunlight, but it is nevertheless true that the greater portion of the light they receive is reflected sunlight. On a bright day the clouds reflect sunlight, and on a dull day

FIG. 19.



the diffused light is also sunlight, which is reflected according to the laws of geometrical optics, and a large per-centage reaches the earth from the clouds. There is also a fair proportion of light from the sky; this is bluer than that reflected or diffused from the weakened sunlight. In cases where the windows of a gallery are in vertical walls, which is the most ordinary case, and have an interrupted view of the horizon, the blue light reflected is comparatively small, the light near the horizon being distinctly more like sunlight than that nearer to the zenith. In galleries lighted like those at South Kensington the light comes from above. The artificial lights to which water-colours are exposed are gas-light, electric arc and incandescent lights. The first and last are very deficient in blue rays (see Fig. 19). You see, for instance, how deficient gas-light is in blue rays compared with sunlight or blue sky. Blue sky, you will notice, possesses hardly any red light whatever.

Now I think you will see why we were justified in exposing our pigments to sunlight instead of skylight. If you know the amount of blue rays that are in any particular light, and the amount of work such rays are capable of performing, it is quite fair to translate the action which one source of light has upon a pigment into the amount of effect from a different source of light. That is to say, if I know what action sunlight will have upon a pigment, then from diagrams such as the above, we can calculate the amount of action which skylight will have, and also the gas-light, whether the intensities of the total light are the same or different.

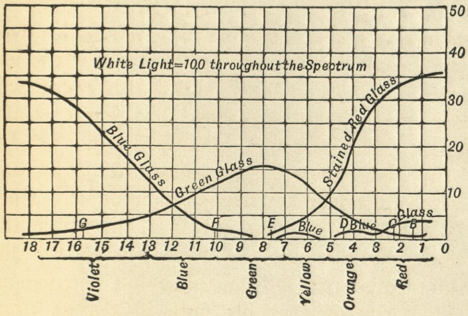
It is now necessary to explain to you how it was that we came to use three kinds of glasses for our experiments to see which part of the spectrum was most effective. As a preliminary, I should like to show you that a pigment may be very rapidly acted upon, although apparently perfectly inappreciably to the eye. I have here two transparent films which were treated with two dyes. Those two films were exposed behind a transparent cross to the electric light for ten seconds, and were then floated over with a silver salt and a developer. From previous experiments we knew that where these particular dyes had been acted upon by light there silver would be deposited on them, and I think you will see that these two show that such is the case. The first film was dyed blue originally, and you will see where the light has acted the silver has deposited upon it. Here is another film, originally red, on which the same thing occurs. I want you to lay this thing to heart. Do not think that because an object does not visibly fade in a year that, therefore, it has not begun to fade at all. A year to one pigment may be the same as 30 seconds to another pigment, and if you expose pigments for a year, which will only fade as much as that particular pigment faded in 30 seconds, then, applying this silver salt, you will probably get exactly the same action after a year's exposure as you did with that shorter exposure on the more fugitive colour.

One more experiment. Here I have a piece of paper which has been impregnated with a silver salt, and has also been dyed with a colour. I want to show you that the smallest action of light on this particular colour will cause the reduction of silver salt. I am going to expose the paper to the spectrum for 10 seconds. [The paper here was developed.] You see in this case that we have a black band corresponding to the absorption spectrum of the dye with which it was dyed. This band is absent where the silver alone without the dye

is acted upon. The dye has been acted upon, and thus caused a reduction of silver to take place where it has been altered, although such alteration is perfectly invisible to the eye.

Now I can show you why we chose red, blue, and green glasses for our experiments. I want you to notice the different parts of the spectrum that these particular glasses absorb. Passing the glasses through the spectrum, the red glass allows the red, and a little bit of yellow and green, to pass (see Fig. 20). With the green glass a great deal of the red is cut off, and all of the violet. With the blue glass you will see that a great deal of the red is cut off. Thus, in the case of the blue glass, we have the blue principally left, in the case of the green the green principally left, and in the case of the red glass we have the red principally left. Now, suppose I put the red glass and the blue glass together, what would happen? We only ought to have a bit of the red of the spectrum left, and if I put the green glass with these

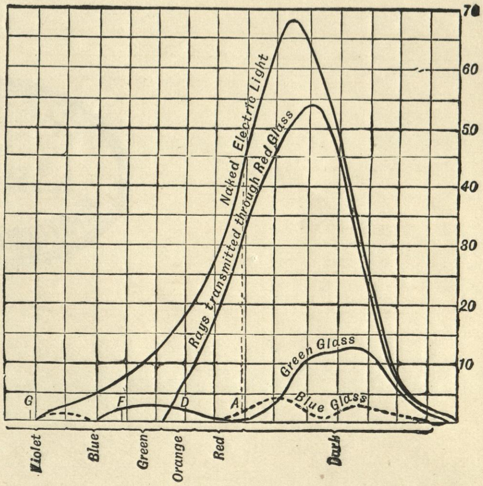
FIG. 20.



we ought to have nothing left, which is the case. In other words, the rays transmitted by those three glasses make up the whole spectrum, so that when using those we are utilising the rays of every part of the visible spectrum. It was for this reason we choose those particular glasses through which to expose our pigments. Fig. 21 shows the heating effect of the light after passing through the different glasses. Notice the dark rays. They are nearly entirely transmitted through the red glass, very slightly through the blue and green glasses. Had the fading of the colours we have examined been due to the dark rays, it ought to have been shown beneath the red glass far more than under the green or the blue glass. This was not the case, as a reference to Table IV. will show. We may, therefore say that the blue, violet, and ultra violet rays are those which are by far the most active in producing a change in the pigments with which we have experimented.

I may say a word or two about the exposures we gave, and the results deduced. We exposed between May, 1886, and the middle of August, and we found that during that time these pigments had 705 hours of bright sunshine. That bright sunshine we reduced to so much sky light, and the total amount of effective sky light received in that time was 1,700 hours. Allowing for overcast skies, and for blue sky light and sun light, we find that these pigments had an average of 2,225 hours of average of blue sky—or, roughly speaking, 2,500. We may now go a step further, and calculate the amount of illumination which a

FIG. 21.



picture shown in a gallery such as those at South Kensington would have during the same period. There is no direct sunlight, and making calculations from photometric observations, and seeing how much light came into the gallery, compared with that outside, we came to the conclusion that to have the effect on these pigments in the galleries which took place in the sunlight, 32 years would have to elapse, supposing the light was always equally bright to that between May and August. But we know it is not equally bright, and we came to the conclusion that it would take 100 years to get the very little fading such as we got outside the laboratory in four months.

Now let us see what would happen to a pigment supposing it were exposed to gas light. Calculating the amount of blue light in such light, and also the total illumination in the

gallery in question, we found it would require at least 2,000 years of continuous exposure for the same amount of effect to take place as occurred in the four months of sunlight exposure. After an exposure of one year and nine months, we have the astonishing result that to obtain fading of the same amount in the colours exposed, it would have taken 485 years of average daylight in the galleries to have got that amount of bleaching. If we had exposed it continuously to gas light, the time required is almost incredible to believe, viz., 9,600 years. With these facts before us I think you will say it is not at all surprising that we chose to use sunlight instead of any other source of light for our experiments. I am afraid that neither Dr. Russell nor myself are good for 480 years, and therefore we preferred to use the shorter time of one year and nine months in order to arrive at the conclusions we did.

The methods of measurement that I have brought before you are for the most part new, but I believe they can escape any very serious criticism. The details of many of the experiments, from which our calculations have been derived, have been published in various papers laid before the Royal Society and the Physical Society. I may say we have the greatest reliance on the accuracy of them.

I have now finished my course of lectures, and I have only to thank you for the great attention which you have paid to me.

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